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GFDL BULLETIN

Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

Advancing the Modeling, Understanding, and Prediction of Weather and Climate

AN EMERGING ASIAN AEROSOL DIPOLE PATTERN RESHAPES THE ASIAN SUMMER MONSOON AND EXACERBATES NORTHERN HEMISPHERE WARMING

npj Climate and Atmospheric Science

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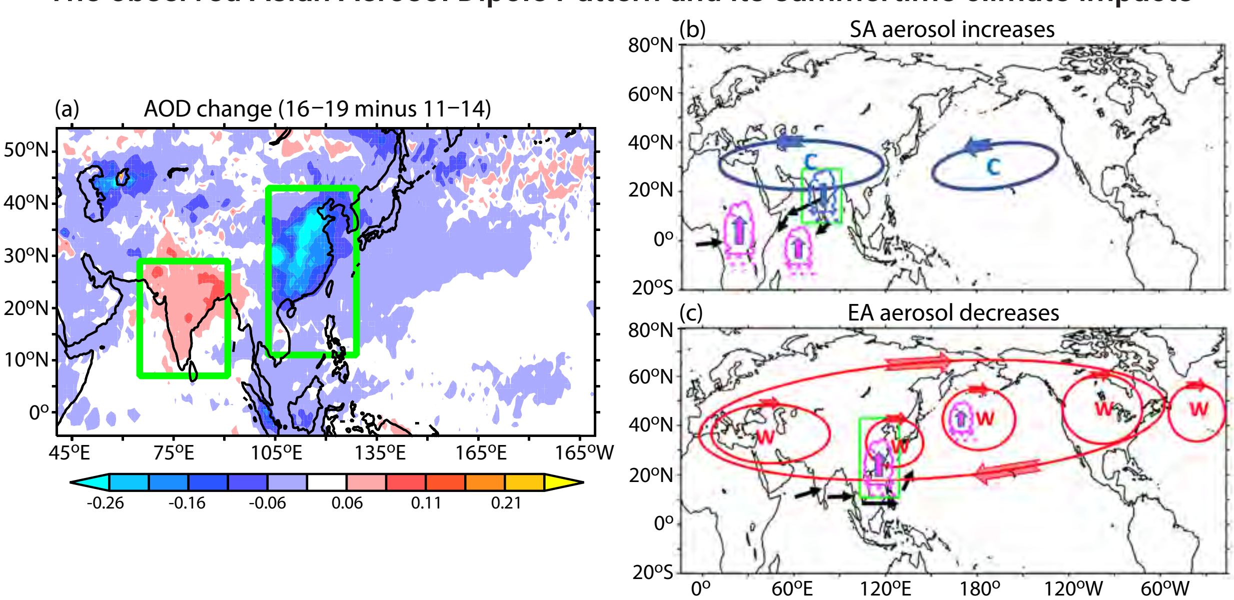
Aerosols, while a public health concern as air pollution, also play a critical role in regulating climate. Using a sophisticated climate model, Xiang et al. examined the regional and global climate impacts due to the aerosol increase in South Asia and the decrease in East Asia since the early 2010s. This is referred to as the "Asian Aerosol Dipole" (AAD) pattern. A notable finding was that South Asia's rising aerosol levels reduced local land summer precipitation changes that, in magnitude, were approximately 2.7 times stronger than the precipitation increases caused by the aerosol decrease in East Asia, with the aerosol-induced radiative forcing in both regions being of similar magnitudes.

The global implications of South Asia's aerosol accumulation were found to be relatively weaker and confined to the tropical region. In stark contrast, East Asia's aerosol depletion has broader and stronger ramifications, prompting a pronounced warming effect across the northern hemisphere, propelled by extratropical westerlies and positive air-sea feedbacks. The quantification of the AAD-induced temperature response was shown to be pronounced based on the estimation of the observed shortwave instantaneous forcing derived from satellite observations. AAD is thus an important driver of the hemispheric warming trend, underscoring the critical role of aerosol patterns in global climate change. The study emphasizes the necessity of integrating region-specific aerosol impacts into climate change adaptation and mitigation strategies, particularly concerning future extreme weather events. The study also shines a new light on the climate effects of Asia's shifting aerosol patterns, advocating for a comprehensive analysis of local and regional aerosol influences. Model-dependent aspects such as the physics accounting for aerosol-climate interactions also require advancements in order to improve the quantification of the impacts.

OAR Goals: Detect Changes in the Ocean and Atmosphere, Drive Innovative Science

The observed Asian Aerosol Dipole Pattern and its summertime climate impacts



(a) The observed aerosol optical depth (550 nm) difference between the period 2016-2019 and 2011-2014. A schematic diagram showing the contrasting climate impacts due to (b) the South Asia aerosol increases and (c) the East Asia aerosol decreases during boreal summer. The upward and downward arrows indicate enhanced and suppressed convection, respectively. The black arrows represent the lower tropospheric wind responses. The blue and red circles denote the upper tropospheric responses. "C" and "W" represent surface cooling and warming, respectively.

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COHERENT MECHANISTIC PATTERNS OF TROPICAL LAND HYDROCLIMATE CHANGE

Geophysical Research Letters *Suqin Q. Duan[1,2], Kirsten L. Findell[3], Stephan A. Fueglistaler[4]*

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Accurate predictions of future changes in hydroclimate over land are essential for society, especially regarding the magnitude and frequency of extreme heat, extreme rainfall, and droughts. The study by Duan et al. addresses crucial gaps in the understanding of land-atmosphere interactions, particularly how different types of extreme weather events are interlinked and how local changes affect the global hydrological cycle. The authors present a "process-based phase space" a tool that organizes the spatial complexity by the climatological aridity index (AI) and the temporal complexity by the daily soil moisture (SM). This methodology allows for a comprehensive yet succinct visualization of model predictions, elucidating the physical relationships between key variables such as SM, evapotranspiration (ET), temperature, and the balance between precipitation and evaporation (P-E). This simplification of the vast and dynamic global data into an integrated overview is facilitated by an understanding of local, daily processes governed by limited supplies of soil moisture and energy at the land surface.

Upon analyzing the changes in these variables over tropical and subtropical land under increasing atmospheric CO_2, the study noted that, while individual model predictions may vary for specific regions, the SM/AI phase space reveals similar patterns of changes across models, though for different percentages of space and time. These patterns highlight hydroclimatic changes corresponding to regimes defined by the non-linear relationship between SM and ET, indicating that the sensitivity of temperature extremes are closely tied to soil moisture levels. Additionally, displaying precipitation changes in the SM/AI phase space highlights a shift in rainfall intensities, with the heaviest rainfall events becoming even more intense in a warming climate. The study further discusses how hydroclimatic changes over land differ from the ocean-centric "wet-gets-wetter, dry-gets-drier" paradigm. The SM/AI framework is also applicable to other climate variables, making it a versatile tool for comparing models, different experimental scenarios, and observational data.

The results obtained point to the possibility of making quantitative theoretical advances in the understanding of Earth's complex hydrological system. Understanding the mechanisms driving extreme temperatures and their connections with the hydrological cycle over land is crucial in the context of future temperature extremes in a warming world.

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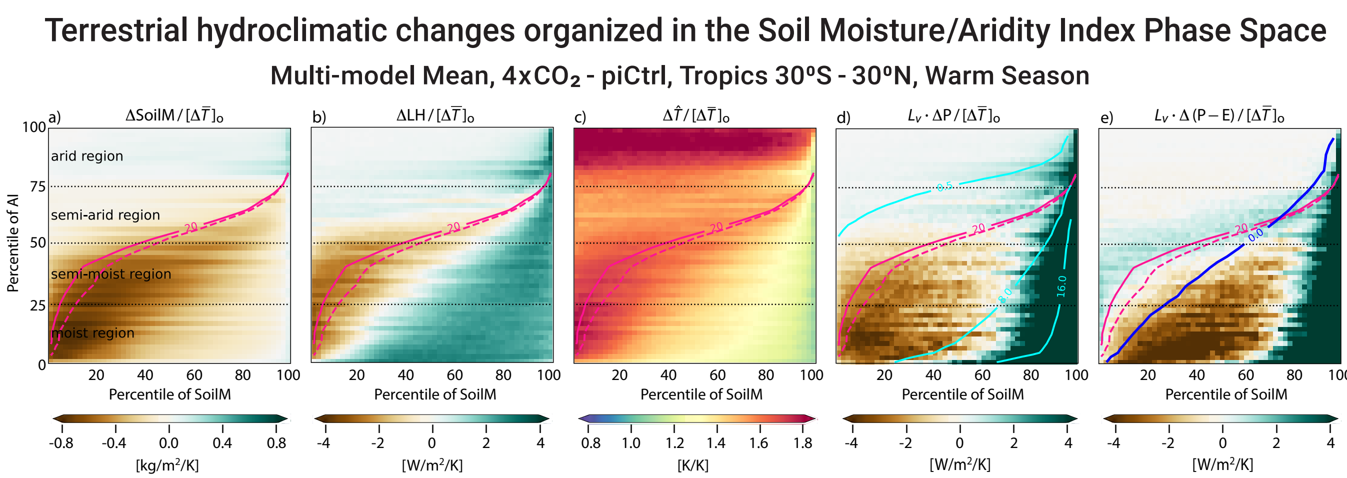

Average changes in soil moisture, latent heat flux (LH, or heat from evapotranspiration capturing both evaporation and transpiration from plants), peak daily temperatures, precipitation, and moisture availability (precipitation minus evapotranspiration) across 16 climate models, comparing a high CO_2 scenario ($4xCO_2$) to a pre-industrial (piCtrl) climate. Changes are benchmarked to tropical ocean warming. Pink lines mark a common soil moisture level in the pre-industrial control (solid lines) and $4xCO_2$ (dashed lines) experiments. This SM level approximates the separation between days where SM limits evapotranspiration (above the pink line) from days where energy availability limits evapotranspiration (below the pink line). Cyan and blue lines, respectively, serve as reference for normal rainfall and the balance of rainfall minus evaporation in the pre-industrial state. Results are for the five-month warm season defined as May through Sept. in the northern hemisphere and Nov. through Mar. in the southern hemisphere.

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IMPACTS OF THE NORTH ATLANTIC BIASES ON THE UPPER TROPOSPHERE/ LOWER STRATOSPHERE OVER THE EXTRATROPICAL NORTH PACIFIC

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Rajat Joshi[1] and Rong Zhang[1,2]

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The interplay between oceanic and atmospheric components plays a crucial role in shaping weather patterns and temperatures around the world. The paper by Joshi and Zhang brings into focus the complex relationship between the North Atlantic Ocean and the atmosphere over the extratropical North Pacific, particularly in the context of the upper troposphere and lower stratosphere (UTLS) during the winter months. Employing state-of-the-art climate models and a comprehensive approach to incorporate the observed ocean data, this research sheds light on the significant impact of North Atlantic Ocean circulation biases on the winter upper atmosphere over the extratropical North Pacific. The foundation of this study lies in incorporating the observed North Atlantic hydrographic data into GFDL's high-resolution climate model version 2.5 (CM2.5). With this approach, the authors effectively corrected the North Atlantic Ocean circulation biases to unravel the wintertime atmospheric impacts.

The research reveals that biases in the North Atlantic significantly reduce the surface heat fluxes released from the North Atlantic into the atmosphere. These changes, in turn, induce negative lower tropospheric temperature anomalies in the mid-latitudes, setting off a chain of reactions that impact storm tracks over the northern hemisphere and the large-scale extreme precipitation over the western United States. A detailed thermodynamic analysis further highlights the critical relationship between the horizontal advection of temperature changes and the adiabatic heating (vertical advection of the mean potential temperature by changes in vertical velocity) in the UTLS over the extratropical North Pacific. The UTLS vertical motion response can provide a rough estimation of the UTLS warming response over the extratropical North Pacific. This study also suggests that a stronger North Atlantic-induced Walker circulation response over the tropical North Pacific contributes to a stronger UTLS vertical motion/temperature response and associated jet stream response over the extratropical North Pacific.

The study also underscores the broader implications of the interconnectedness of global oceanic and atmospheric systems and lays a reliable foundation for predicting the impacts of North Atlantic Ocean circulation changes on global weather and climate systems.

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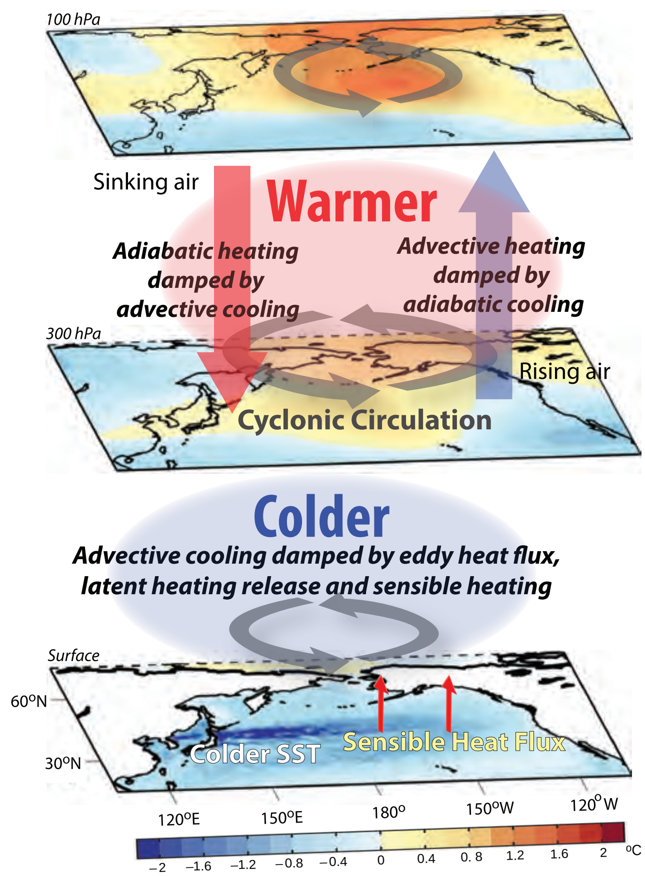
The thermodynamic process sustaining warming in the upper troposphere/lower stratosphere (UTLS) and cooling in the lower troposphere over the extratropical N. Pacific in response to the N. Atlantic cold biases:



In the surface and lower troposphere, the North Atlantic-induced cooling response over the western and central extratropical North Pacific (blue shading) is sustained by reduced horizontal advection. The enhanced convergence of eddy heat flux, latent heating release, and sensible heat flux (red arrows at the surface) tend to damp it.

In the upper troposphere/lower stratosphere (UTLS; 100-300 hPa), the North Atlantic-induced warming response (red shading) is sustained by enhanced adiabatic (horizontal advective) heating and damped by enhanced horizontal advective (adiabatic) cooling over the western (eastern) extratropical North Pacific. The sinking (rising) response associated with the enhanced adiabatic heating (cooling) is represented as red (blue) arrow.

THE ROLE OF UPPER-OCEAN VARIATIONS OF THE KUROSHIO-OYASHIO EXTENSION IN SEASONAL-TO-DECADAL AIR-SEA HEAT FLUX VARIABILITY

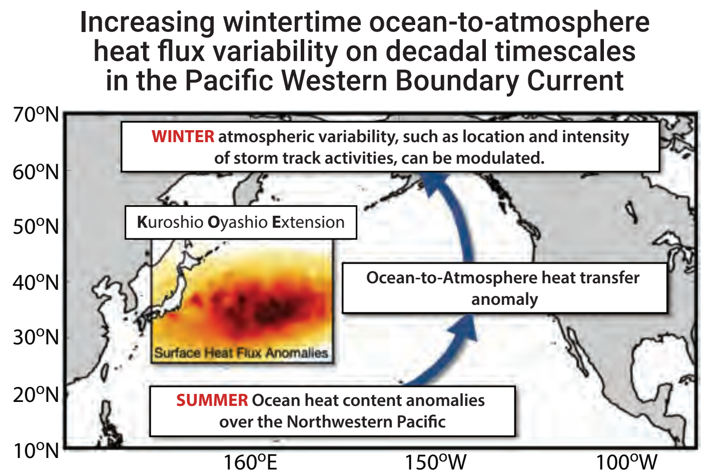
npj Climate and Atmospheric Science

Youngji Joh[1], Thomas L. Delworth[2], Andrew T. Wittenberg[2], Xiaosong Yang[2], Anthony Rosati[2,3], Nathaniel C. Johnson[2], Liwei Jia[2,3]

DOI: s41612-023-00453-9

Ocean Western Boundary Current (WBC) systems play an integral role in the climate system by transporting heat, salt, mass, and biogeochemical elements meridionally, as well as within the ocean's subsurface. These currents have a strong influence on the exchange of moisture and heat between the ocean and atmosphere. The Kuroshio-Oyashio Extension (KOE), a key WBC system in the North Pacific, is known for its significant decadal variability and predictability. It is closely linked to strong air-sea interactions and marked by notable anomalies in ocean heat content, sea surface temperature (SST), and sea surface height (SSH) in the region.

In examining the KOE's variability, the Joh et al. (2023) study focused on how low-frequency fluctuations of the KOE's upper ocean interact with the atmosphere across seasonal timescales, and how these interactions have shifted under recent warming trends. By leveraging satellite data and observational reanalysis, the authors found a distinct seasonality of the decadal variations of ocean heat content and SSH in the KOE region associated with air-sea coupled processes. The KOE heat flux anomalies linked to subsurface ocean variability were most pronounced during early winter (Nov. to Jan.). The authors found that upper-ocean heat content anomalies that were accumulated during the previous summer play a crucial role in affecting low-level atmospheric circulation. There are corresponding changes to the spatial evolution of the coupled air-sea feedback from summer to fall, leading to significant variability in ocean-to-atmosphere heat transfer during the early winter. Further, the study noted an increase in the intensity of seasonal and decadal variations of KOE heat fluxes over the last several decades. A statistical analysis showed a substantial increase in wintertime KOE heat flux variability characterized by an approximately 10-year timescale since the mid-1980s. The authors hypothesize that the increased variance of KOE heat fluxes in wintertime on a decadal scale might be attributed to increased oceanic variability, such as from ocean temperature variations, rather than changes in atmospheric conditions like wind speed.



The relationship between decadal variations of ocean heat content within the Kuroshio-Oyashio Extension (KOE) region and the seasonal exchange of heat between the ocean and the atmosphere. The inner box provides a detailed representation of the spatial pattern of KOE heat flux variability. This pattern is closely linked to warm ocean temperature anomalies over the KOE, which serves as an indicator of the transfer of heat from the ocean to the atmosphere.

The main findings of seasonality and long-term changes in decadal variations of KOE heat flux anomalies from the study may provide critical clues into the ocean's role in modifying overlying atmospheric circulations, such as extratropical storm tracks, in a changing climate. An improved understanding of the processes governing KOE variations and associated air-sea interactions is an essential component in improving predictions of the midlatitude ocean-atmosphere coupled system and associated climate variability, carrying significant societal impacts.

OAR Goals: Detect Changes in the Ocean and Atmosphere, Make Forecasts Better

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Dr. Tom Delworth of GFDL Awarded the 2023 Presidential Rank Award

The 2023 Presidential Rank Award celebrates Dr. Delworth's exemplary leadership, integrity, and dedication to deepening our understanding of Earth's climate system.

Dr. Tom Delworth, Senior Scientist and Leader of GFDL's Seasonal to Decadal Variability and Predictability division, has been awarded the 2023 Presidential Rank Award for his contributions to climate science, especially in the areas of climate variability and predictability. His expertise in developing advanced climate models has been crucial to enhancing GFDL's climate forecasting capabilities. With nearly 200 peer-reviewed papers, his research has significantly influenced the scientific community. Dr. Delworth's influence extends beyond GFDL as a Fellow of both the American Meteorological Society (AMS) and the American Geophysical Union (AGU), and as a recipient of the AGU's 2021 Bert Bolin Award for Climate Research Excellence. He is also a dedicated educator, lecturing at Princeton University and mentoring emerging climate scientists.

Ronald Stouffer Honored with 2024 Syukuro Manabe Climate Research Award

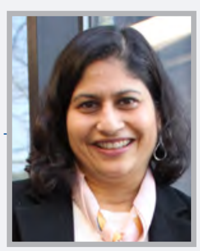
Ronald Stouffer, retired Senior Research Scientist at GFDL, has been awarded the 2024 Syukuro Manabe Climate Research Award by the American Meteorological Society (AMS) for his significant contributions in the development and application of coupled atmosphere-ocean climate models. Starting his career at GFDL in 1977 with Syukuro Manabe, Stouffer's work has been pivotal in understanding climate dynamics, climate variability and change, and the Earth's response to greenhouse gas forcings. He is a Fellow of AMS (2007) and American Geophysical Union (AGU, 2012), and has been a key author for the Intergovernmental Panel on Climate Change reports.

Dr. Stephen Griffies, Physical Scientist at GFDL, has been named to the **2023 Clarivate Analytics Highly Cited Researchers List**, a prestigious recognition, for his exceptional influence in the field of physical oceanography and climate science. This annual list identifies international researchers who have demonstrated significant influence in their chosen fields over the past decade, as evidenced by their high citation records.

Dr. Griffies' work, especially in developing advanced ocean circulation models, has been pivotal in advancing our understanding of ocean dynamics and their integral role in the global climate system. His recognition also includes being a Fellow of AGU (2017) and a recipient of the Nansen Medal from the European Geosciences Union (2014), underscoring his substantial contributions to the scientific community and his excellence in climate research.

GFDL Scientists Honored for Climate Science Excellence by AGU in 2023

Dr. Rong Zhang, Senior Scientist and Leader of GFDL's Ocean and Cryosphere Division, has been elected a **2023 Fellow of AGU** for her research on the Atlantic Ocean and its global climate impact. A leading expert on the Atlantic Meridional Overturning Circulation and Atlantic Multidecadal Variability, her work has enhanced understanding of multidecadal climate variability and its social and economic impacts. A fellow of AMS and the 2021 AMS Bernhard Hauwitz Memorial Lecturer, her influential roles include teaching in the Atmospheric and Oceanic Sciences Program at Princeton University, mentoring, and editorial responsibilities for the Journal of Climate.



Dr. Vaishali Naik, Research Physical Scientist, has received the **2023 Piers J. Sellers Global Environmental Change Mid-Career Award** from AGU for her key contributions to advancing the knowledge on chemistry-climate interactions. Authoring over 100 peer-reviewed papers and coordinating lead author for the latest IPCC reports, she has been instrumental in the development of GFDL's atmospheric chemistry model and has provided new insights into the climate impacts of aerosols and air pollutants.